NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 2327

FATIGUE TESTING MACHINE FOR APPLYING A SEQUENCE OF LOADS OF TWO AMPLITUDES

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National Bureau of Standards

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SUMMARY

This report describes the construction, the operation, and the calibration of two nominally identical fatigue testing machines built at the National Bureau of Standards. These machines provide a means of applying to a specimen a sequence of two sinusoidally varying axial loads of different amplitudes with the mean load remaining constant, each load being applied for a predetermined number of cycles.

It is possible to measure continuously the loads once established to an accuracy of ±3 percent.

A few preliminary tests made with these machines on a sheet material indicated that the loads once set remained constant to within ±1 percent for the necessary number of loading cycles.

INTRODUCTION

In view of the fact that service fatigue loads on aircraft structures usually have continuously varying amplitudes, it is desirable to extend the knowledge of the effect of fluctuating loads on the fatigue properties of materials used in aircraft construction.

It has been well-established (references 1 to 15) that subjecting certain ferrous and aluminum alloys to alternating loads in which the stress amplitude fluctuates produces pronounced effects on the fatigue properties of these materials. For example, Kommers (reference 1) found in tests of open-hearth and ingot irons that the application of stresses slightly below the original endurance limits resulted in increases up to 24 percent of the original endurance limits. In addition, he found that applying successively increasing increments of understress to annealed ingot iron specimens raised their original fatigue lives at higher stresses by as much as 23,500 percent.

The mechanism by which the phenomena associated with fluctuating fatigue loads occur is unknown, but several theories (references 9 to 11) have been advanced which attempt to correlate the gross effects of these fluctuations in the stress amplitude with the fatigue properties of materials so that the life of a material under the usual service conditions might be more closely predicted. None of these theories seem adequate inasmuch as they fail to account completely for experimental evidence obtained in this field. The principal phenomenon which is not included in the theories is that of the effects of understressing.

Information on the effects of fluctuating fatigue loads on the fatigue properties of materials can be obtained with conventional fatigue machines by changing the stress amplitude manually, but this procedure is tedious and on certain types of fatigue machines it is difficult to reestablish a predetermined load to the necessary degree of accuracy. Therefore, two nominally identical machines have been constructed which are capable of subjecting sheet-metal specimens to a prescribed number of cycles of axial fatigue load, automatically changing the load amplitude for another prescribed number of cycles, and then repeating the entire loading schedule until failure of the material occurs. By means of these machines, it is possible to study systematically the effects of a wide range of stress-cycle combinations on the fatigue strengths of sheet materials. The machines are capable of applying pulsating as well as completely reversed axial load.

The construction of these machines was conducted at the National Bureau of Standards under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

DESCRIPTION OF MACHINES

The machines were designed and constructed by Mr. William C. Brueggeman, formerly of the National Bureau of Standards, and are modeled after the lever-type machine described in reference 16 as machine a. The machines are capable of testing specimens of sheet materials, the maximum over-all dimensions of which are about 2 inches by 6 inches by 0.1 inch, up to a maximum load of ±2000 pounds. Figure 1 is a schematic diagram of the side elevation of one of the machines. Both machines are mounted in a common frame. Figure 2 shows the machines and the auxiliary equipment used for the measurement and monitoring of the maximum load on the specimens and figure 3 is a more detailed photograph of the side elevation of one of the machines.

The specimens are held by friction between the jaws and are axially loaded by means of the loading lever (fig. 3). The lever is provided

with a crossed flexure plate pivot, which is not shown. This pivot allows the lever to rotate freely but restrains it against translation. The driven end of the lever is guided in a vertical plane by means of the cross head shown in figure 4. The end of the lever is driven in nearly simple harmonic motion by means of the crank and connecting rod shown in figure 4. The connecting rod is attached to the lever and crank through self-alining spherical-seated shell bearings.

The crank is constructed to allow its throw, hence the load amplitude on the specimen, to be changed during operation by means of a linkwork within the crank housing and crankshaft which is actuated by the double-acting compressed-air cylinder shown in figure 3. The maximum and minimum magnitudes of the crank throw are established by means of the adjustable stop nuts on the crank (fig. 4). To aid in setting the throw accurately, a vernier, reading to 0.0025 inch, was built into the crank housing. Once the stop nuts are set, the air piston forces the crankpin up against one of the nuts, establishing one crank throw; then, upon reversal of direction of motion of the air piston, the crankpin is forced against the other nut, thus setting the other crank throw. The crankpin is held solidly against the stop nuts by the air pressure in the cylinder. A pneumatic switch is provided in the compressed-air supply line to stop the machines should the air pressure drop below the safe operating value.

Dial indicators, shown in figure 4, were mounted on the machine frame to aid in centering the levers at the midpoints of their excursions before inserting the test specimens. If the levers are at the midpoint of their excursions before the specimens are clamped in the machines, the measured mean load on the specimens is very nearly zero.

The position of the crank is controlled through a suitable circuit closed by means of microswitches which are actuated by a reduction gear shown in figure 5. The gear train is coupled to the cycle countershaft by a chain drive. The train consists of simple worm and worm-wheel combinations which allow speed reductions from the countershaft speed from 1:1 to 1:10,000,000 to be chosen in integral powers of 10.

The disk, also shown in figure 5, is coupled directly to any selected shaft in the gear train. The disk contains two lugs on each face at the rim. The lugs pass over the microswitch actuating bars (fig. 5) during one revolution of the wheel. When a lug depresses its microswitch actuating bar, the circuit is closed and the air piston drives the crankpin against one stop nut, thus setting the corresponding throw; then, upon further rotation of the disk, the other lug passes over its microswitch actuating bar, the crankpin is driven against the other stop nut, and the throw is changed accordingly. The angular interval between the lugs is adjustable so that the number of cycles between changes in the throw can be set to values other than integral powers of 10.

Analysis of the motion of the crank system shows that, regardless of the initial mean load set on the specimen, a change in the crank throw does not affect the mean load so long as the specimen is loaded in its elastic range. Thus, the machines can be used conveniently for studying the effects of a sequence of pulsating or incompletely reversed loads of different amplitudes on the fatigue properties of materials.

The load on the specimen is measured in terms of bending strain in the lever by means of two wire resistance strain gages located on the top and bottom extreme fibers of the lever, as shown in figure 3. The output from these gages is passed into a modified SR-4 portable strain indicator and an oscilloscope by means of a circuit designed to allow measurement of static strain or of the extreme values of the steady-state dynamic strain in the wire gages on the lever. In addition, it is possible to observe the shape of the amplified but unrectified signal from the strain gages. Such an observation permits a study of the force-time relationship applied to the specimen. The load-measuring circuit is such that the difference in the strain-indicator readings is proportional to the load.

Five levers of various stiffnesses were made from heat-treated SAE 8630 steel. The levers have capacity loads ranging from ±420 to ±2000 pounds.

Each machine is driven with a 1-horsepower, 60-cycle, three-phase motor operating at 1725 rpm and is connected with a V-belt to the crank housing. Suitable speed reduction is provided by correctly choosing the diameters of the pulley on the motor shaft and the crank housing in order to operate the levers at approximately 1000 cycles per minute. The machines are equipped with cut-off circuits so that the motors are stopped upon failure of the specimens.

OPERATION OF MACHINES

Assume that it is desired to subject a specimen to a completely reversed load (mean load is equal to zero) $\pm P_1$ for N_1 cycles, followed by another completely reversed load with a different maximum amplitude $\pm P_2$ for N_2 cycles, and that the entire cycle of loading is to be repeated until failure of the specimen occurs.

Using the technique described in reference 17, the specimen is placed between lubricated steel guides shown in figure 6, which prevent buckling under the compressive loads, and one end of the specimen is clamped in the moving (lower) jaw of the machine shown in figure 7. The values of the throw are determined from auxiliary curves of throw against load for a particular type of specimen. The maximum and minimum values

of the crank throw are established with the stop nuts on the crank. The midpoint of the travel of the driven end of the loading lever is then established with the dial indicator and the lever is set at its midpoint. The fixed upper jaw (fig. 7) of the specimen holder is then clamped. This technique gives mean loads which differ from zero by less than 1 percent of the maximum load. For zero mean load, the angular midpoint of the crank is not the midpoint of the displacement of the end of the loading lever and so the zero load position of the loading lever must be determined from its displacement. The dial indicator is removed before the machine is turned on.

The disk (fig. 5) is loosened and the lug normally tripping the P_1 relay is placed so that it depresses the actuating bar on the relay microswitch. From the relationship of the gear train to the disk, it can be seen that

$$N_1 + N_2 = \text{An integral power of 10}$$

since one revolution of the disk corresponds to $N_1 + N_2$ cycles of load and one revolution of the disk must correspond to integral-power-of-10 revolutions of the cycle countershaft. However, it is possible through establishing various angular spacings between the lugs on the disk to vary N_1/N_2 through a wide range of values.

The static tension and compression loads on the specimen are measured to insure that the mean load is very nearly zero. The machine is then turned on, the maximum load excursion is measured, and the specimen is stressed at a maximum load $\pm P_1$ for N_1 cycles. After N_1 cycles, the disk (fig. 5) has rotated until the other lug depresses its microswitch, thereby actuating the air piston and driving the crankpin against the other stop nut, changing the load to $\pm P_2$. The maximum load excursion at $\pm P_2$ is measured. The machine then operates for N_2 cycles, whereupon the first lug has completed one revolution and depresses its microswitch returning the load to $\pm P_1$. This sequence may be continued until failure of the specimen occurs.

CALIBRATION OF MACHINES

Two of the five load levers were calibrated. Lever 1 has a capacity of ±2000 pounds and lever 2 has a capacity of ±1100 pounds. The calibration consisted of determining the relationship between the maximum output of the SR-4 strain gages on the levers and the measured maximum load between the specimen jaws with the machine operating normally.

The applied load was measured with an aluminum-alloy dynamometer of 1.5- by 0.125-inch cross section inserted in the jaws of the machine. This dynamometer was equipped with a pair of 2-inch Tuckerman optical strain gages capable of measuring dynamic strain in the dynamometer equivalent to a load of ±10 pounds. The dynamometer was calibrated statically in a standard hydraulic testing machine with a 2000-pound range. The curves of load against strain from these data were assumed linear and their slopes were determined by least squares. In the determination of the slopes, all of the error was assigned to the strain measurement although the hydraulic testing machine was accurate to only 1/2 percent in its load range of 200 to 2400 pounds and therefore some of the error was due to load measurement. The least-squares slopes for the two tensile calibrations of the dynamometer were 201.0×10^4 and 201.9×10^4 pounds. The least-squares slopes of two compression calibrations of the dynamometer were 199.9×10^4 and 200.9×10^4 pounds. For use in calibrating the fatigue machines the average least-squares slope of the four calibrations of the dynamometer, 200.9×10^4 pounds, was used. The static calibrations of the dynamometer are shown in figure 8 with the average least-squares curve indicated. Figure 9 shows the difference curves for the individual tensile and compressive calibrations of the dynamometer obtained from the measured dynamometer loads and those calculated from the average least-squares slope.

The dynamometer was then clamped in the fatigue machine jaws with the lever in the zero position as determined by the dial indicator. The machine was operated at various crank throws and the excursions of the Tuckerman gages and the SR-4 gages were observed. The sensitivity of the SR-4 gage reading circuit was better than 1/400 of the maximum load.

Figures 10 and 11 show the calibration curves for the two levers. The slopes of the least-squares curves of dynamometer load against SR-4 strain-indicator divisions for runs 1 and 2, M_1 and M_2, respectively, were for lever 1:

$$M_1 = 75.55 \text{ lb/SR-4 division}$$

$$M_2 = 75.76 \text{ lb/SR-4 division}$$

and for lever 2:

$$M_1 = 65.31 \text{ lb/SR-4 division}$$

$$M_2 = 65.77 \text{ lb/SR-4 division}$$

The average slope of these curves was 75.65 pounds per SR-4 division for lever 1 and 65.54 pounds per SR-4 division for lever 2.

Figure 12 shows the difference curves for the individual calibrations of the SR-4 load-measuring circuit obtained from the loads indicated by the dynamometer and those calculated from the average least-squares slope. It is seen that over the load range the differences, representing the errors in the calculated loads, are less than ±3 percent of the corresponding load amplitudes.

The strain-time relationship for the strain gages on the levers was observed to be sinusoidal.

TESTS

Tests under completely reversed axial load were made on 16 specimens of alclad 75S-T aluminum-alloy sheet 0.064 inch thick with a 0.5-inch reduced section. The specimens were tested in groups of four, each set of four beginning with a constant high stress specimen, then a high-low stress sequence specimen, then a constant low stress specimen, and finally a low-high stress sequence specimen. The unit loading sequence consisted of 10 cycles at high stress and 40 cycles at low stress.

The extent to which the fatigue machine maintains its load after setting the eccentricity can be judged to some extent from table 1 since the eccentricity values were not adjusted during this series of tests. The measured low loads for these tests varied from 980 to 1000 pounds and the measured high loads ranged from 1320 to 1330 pounds. Small variations in the cross-sectional areas of the specimens add to the variation in stresses. Additional information is given in table 2 which shows loads measured on a specimen during nine alternations from high to low load amplitude. It is seen that the stress in the specimen remained constant to ±1 percent of the average stress.

CONCLUDING REMARKS

Two nominally identical fatigue testing machines were described that provide a means of applying to a specimen a sequence of two sinusoidally varying axial loads of different amplitudes with the mean load remaining constant, each load being applied for a predetermined number of cycles.

It is possible to measure continuously the loads once established to an accuracy of ±3 percent.

A few preliminary tests made with these machines on a sheet material indicated that the loads once set remained constant to within ±1 percent for the necessary number of loading cycles.

National Bureau of Standards
Washington, D. C., May 24, 1950

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TABLE 1.- RESULTS OF PRELIMINARY TESTS ON SIXTEEN 0.064-INCH-THICK 75S-T ALCLAD

ALUMINUM-ALLOY SHEET SPECIMENS

Specimen	Stress sequence	High stress amplitude (lb/sq in.)	Low stress amplitude (lb/sq in.)	Total cycles at high stress	Total cycles at low stress	Total cycles to failure
M-54	Low only	----------	31.5×10^3	------	47,550	47,550
M-62		----------	31.5	------	45,150	45,150
M-76		----------	31.3	------	46,460	46,460
M-79		----------	31.2	------	53,410	53,410
M-72	High only	41.5×10^3	----------	14,580	------	14,580
M-64		42.4	----------	14,820	------	14,820
M-75		41.6	----------	15,640	------	15,640
M-78		41.6	----------	16,150	------	16,150
M-71	From low to high	41.4×10^3	31.2×10^3	6,700	26,800	33,500
M-74		42.5	31.7	6,290	25,180	31,470
M-77		41.8	31.4	6,840	27,390	34,230
M-81		41.7	31.3	7,470	29,910	37,380
M-60	From high to low[1]	42.3×10^3	31.6×10^3	5,790	23,150	28,940
M-65		42.7	32.1	5,070	20,260	25,330
M-73		42.3	31.6	5,260	21,030	26,290
M-82		41.5	31.1	5,920	23,670	29,590

[1]Loading sequence consisted of 10 cycles at high stress and 40 cycles at low stress.

TABLE 2.- CONSISTENCY OF DYNAMIC-STRESS MEASUREMENT[1]

IN TEST OF A 0.064-INCH-THICK 75S-T ALCLAD

ALUMINUM-ALLOY SHEET SPECIMEN

Stress	Maximum dynamic stress[2] (lb/sq in.)	Number of cycles
Low	31,100	0-2,000
High	42,700	2,000-2,700
Low	31,000	2,700-4,700
High	42,600	4,700-5,400
Low	31,000	5,400-7,400
High	42,600	7,400-8,100
Low	31,000	8,100-10,100
High	42,700	10,100-10,800
Low	31,400	10,800-12,800

[1]Lever 2 was used in obtaining measurements.

[2]Stress measured during cycle increment.

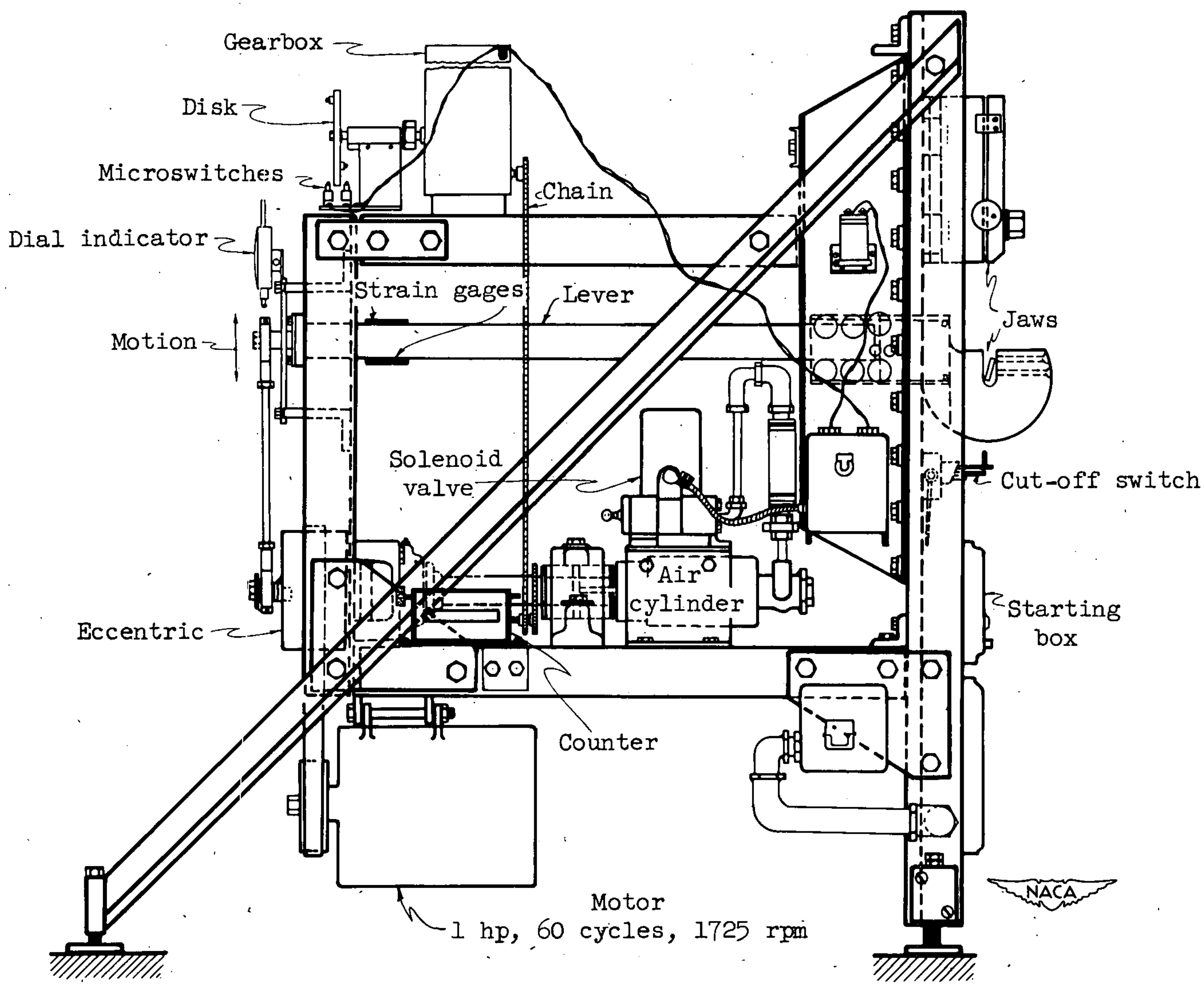

Figure 1.- Schematic diagram of side elevation of fatigue testing machines.

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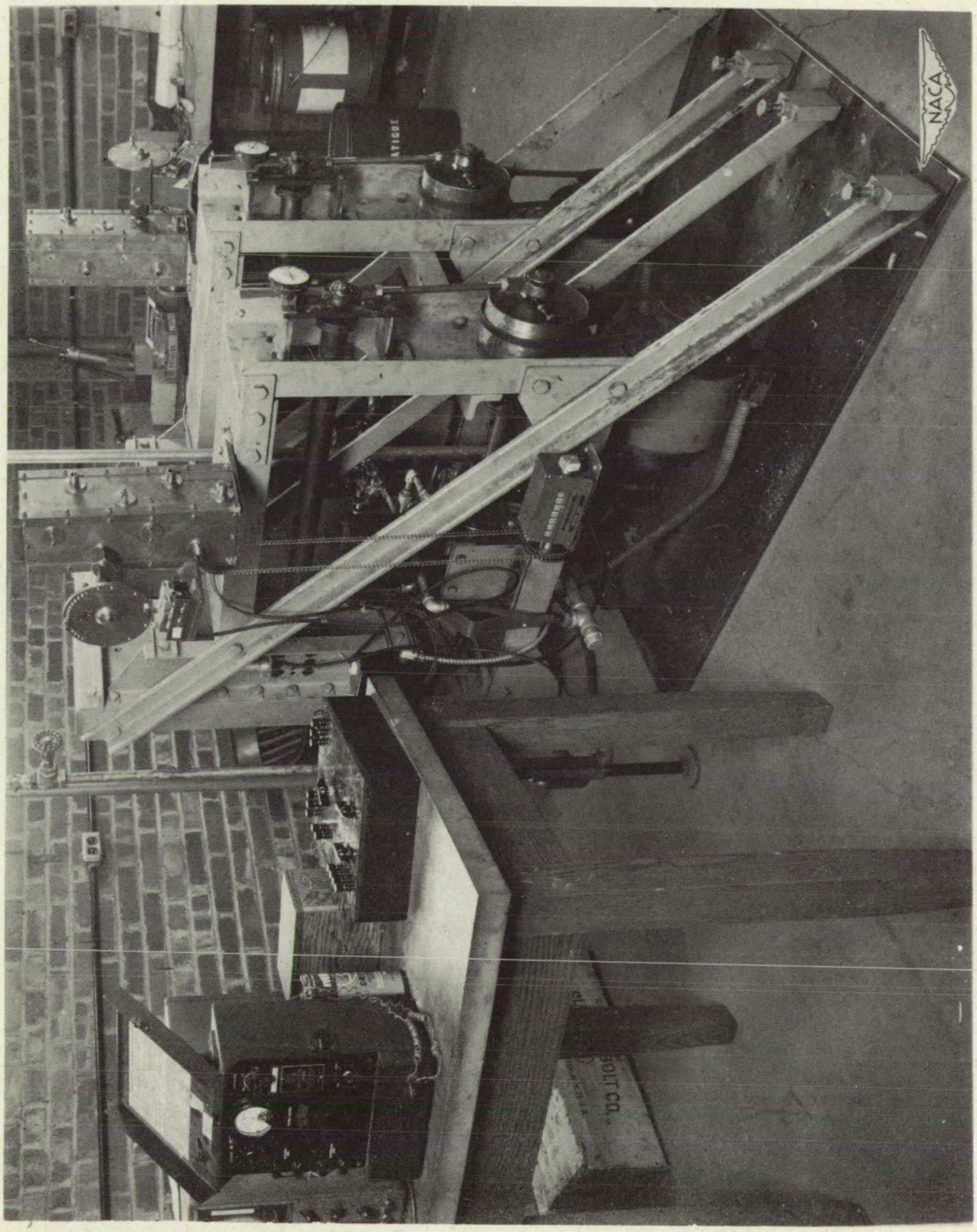


Figure 2.- General view of fatigue testing machines and auxiliary equipment.

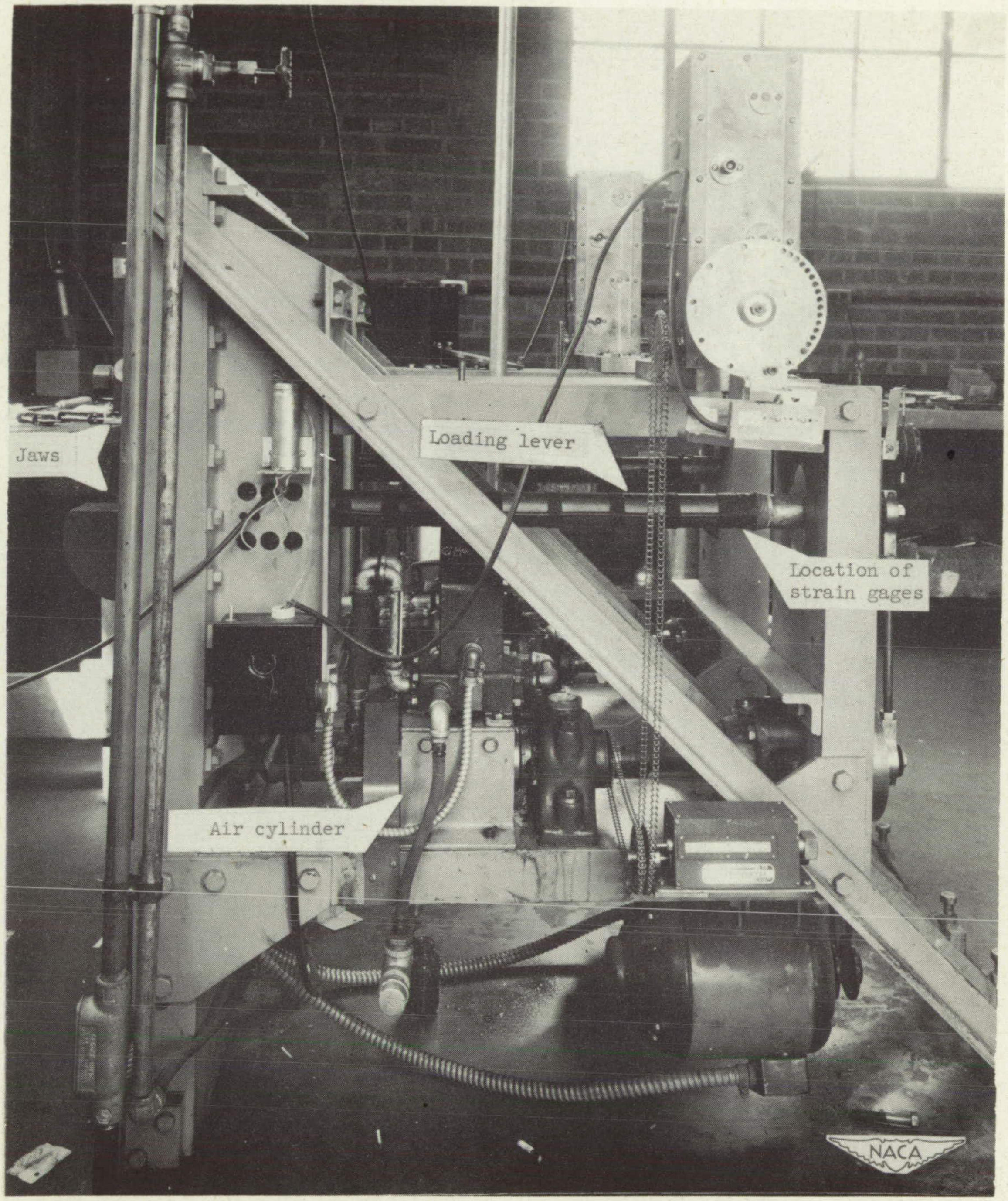


Figure 3.- Detailed view of side elevation of fatigue testing machines.

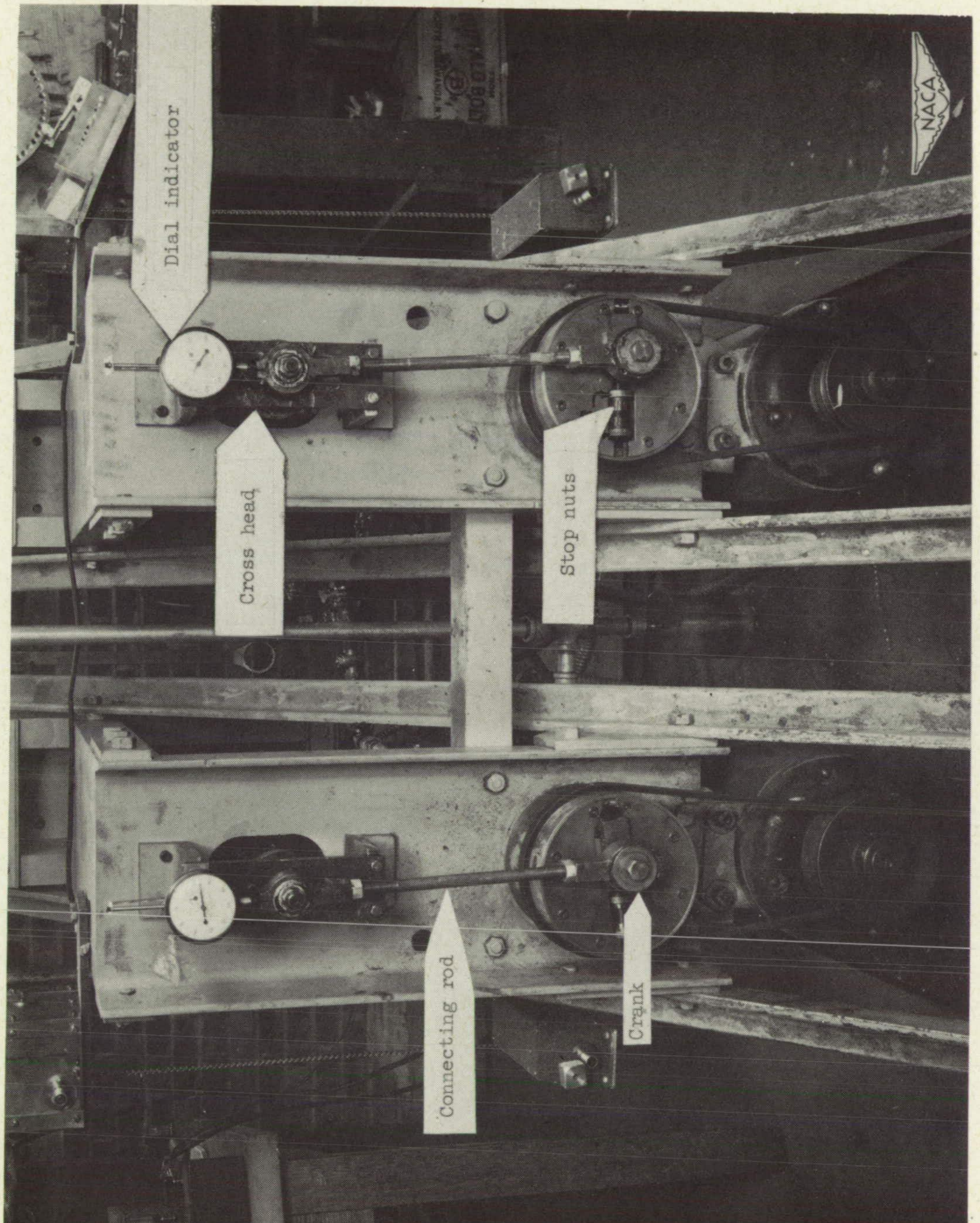


Figure 4.- Driving linkages of fatigue testing machines.

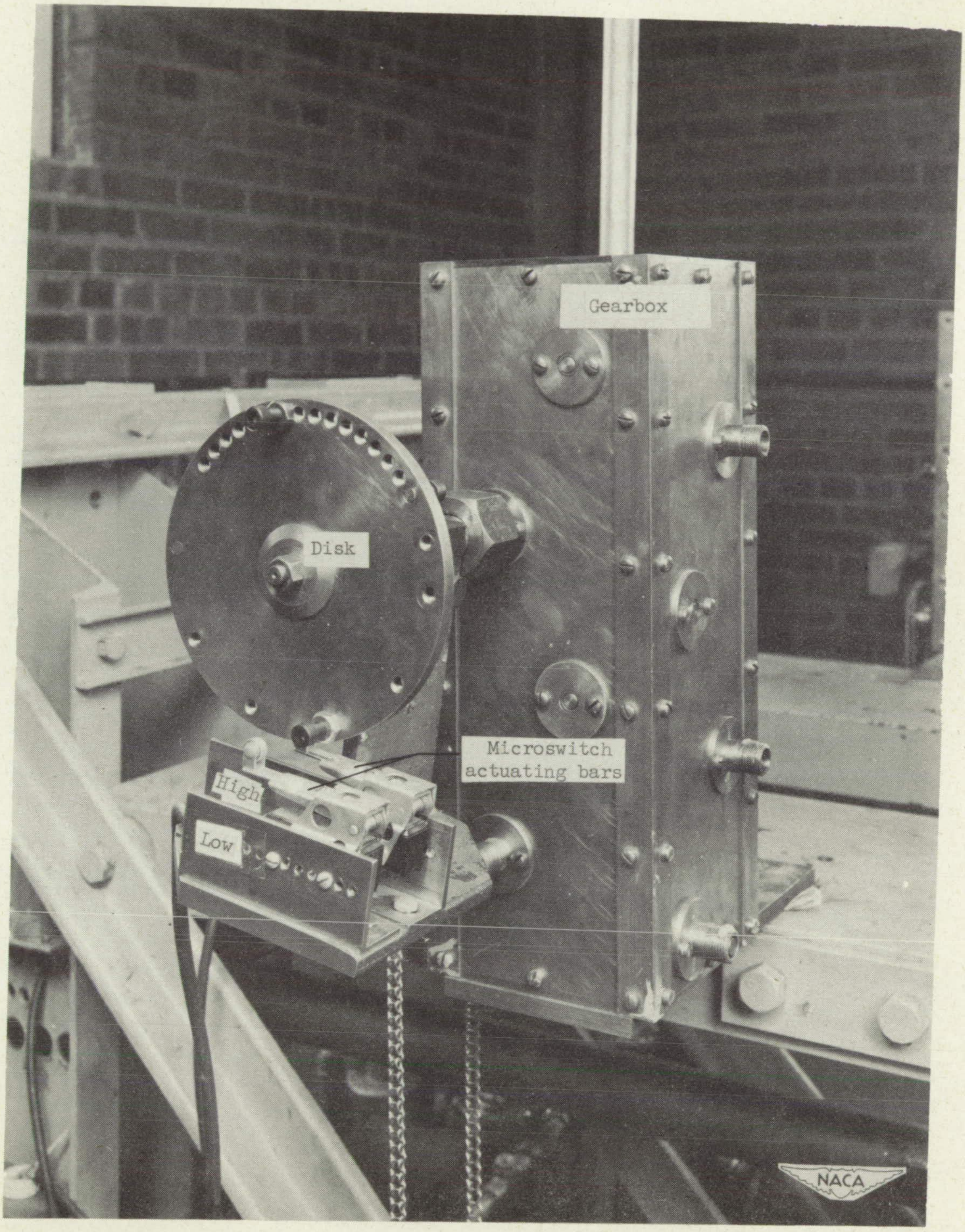


Figure 5.- Load amplitude control mechanism of fatigue testing machines.

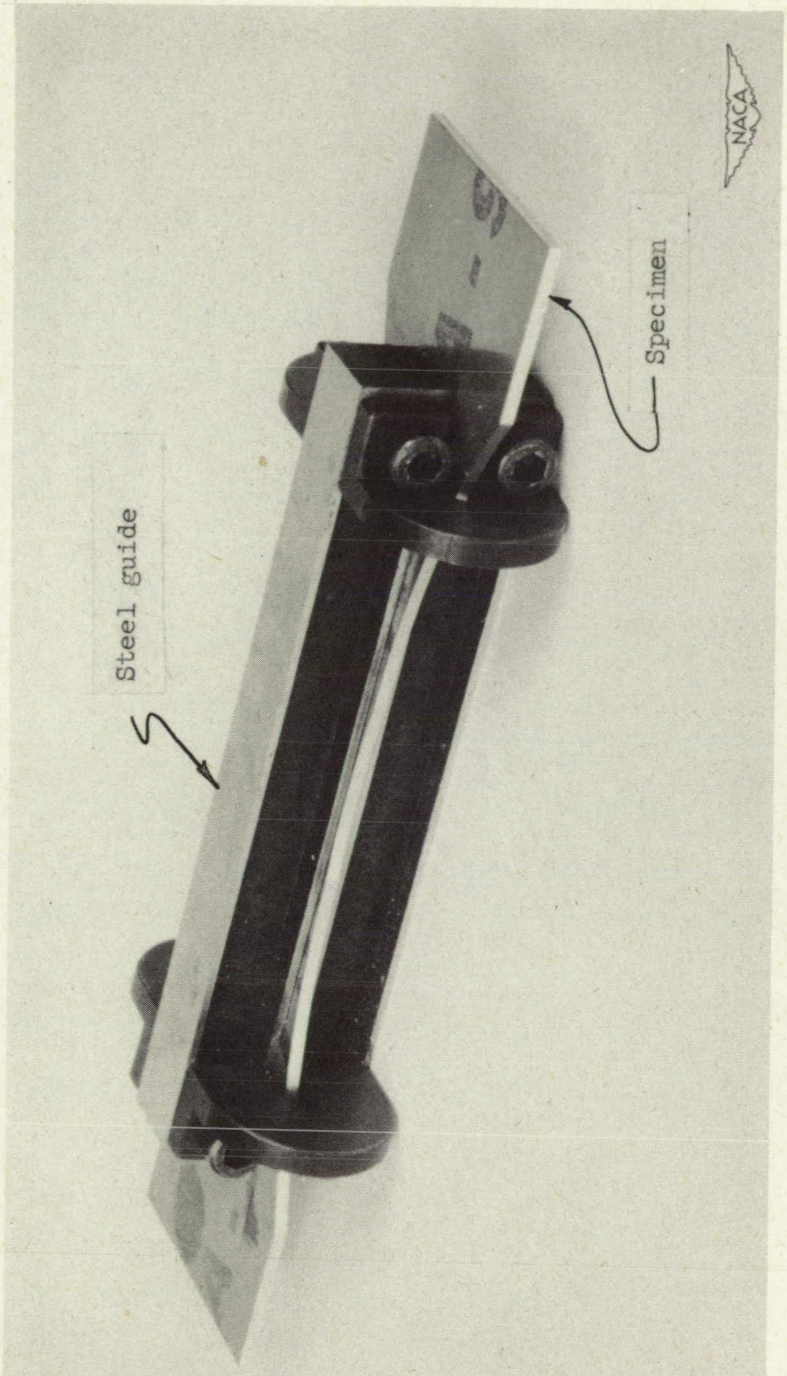


Figure 6.- Lubricated steel guides for specimens tested.

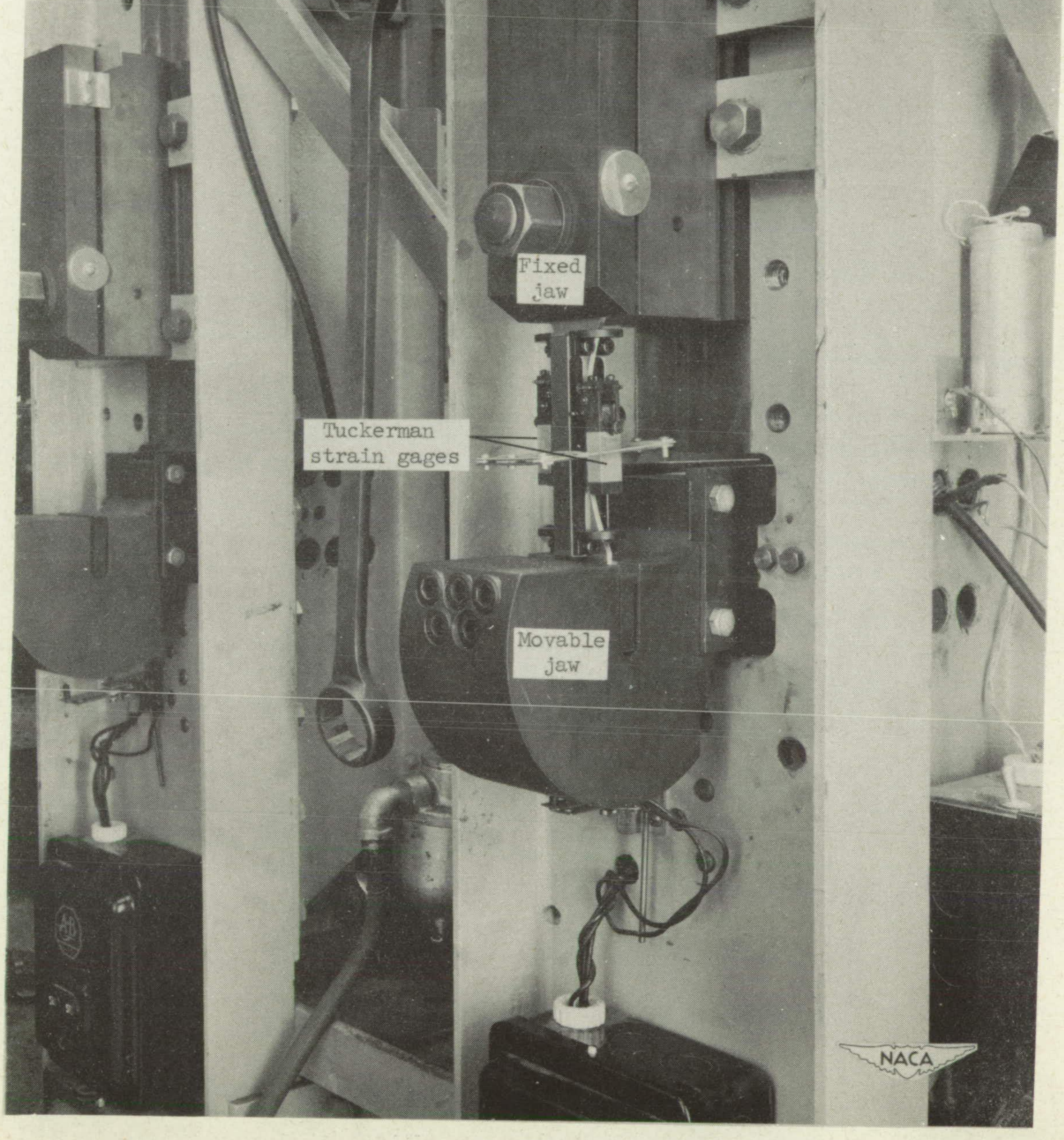


Figure 7.- Specimen clamped in fatigue testing machine.

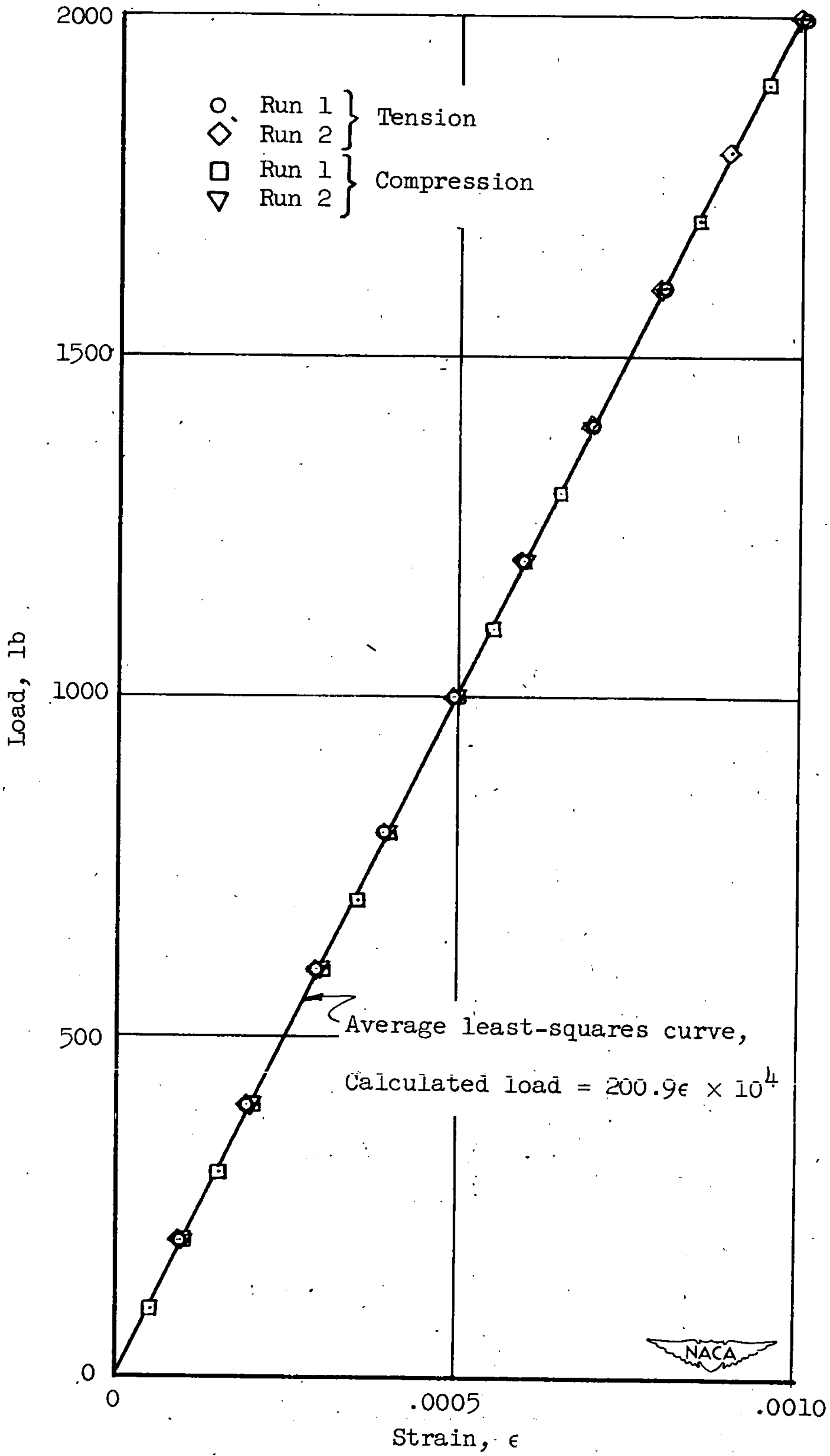


Figure 8.- Static calibration of dynamometer.

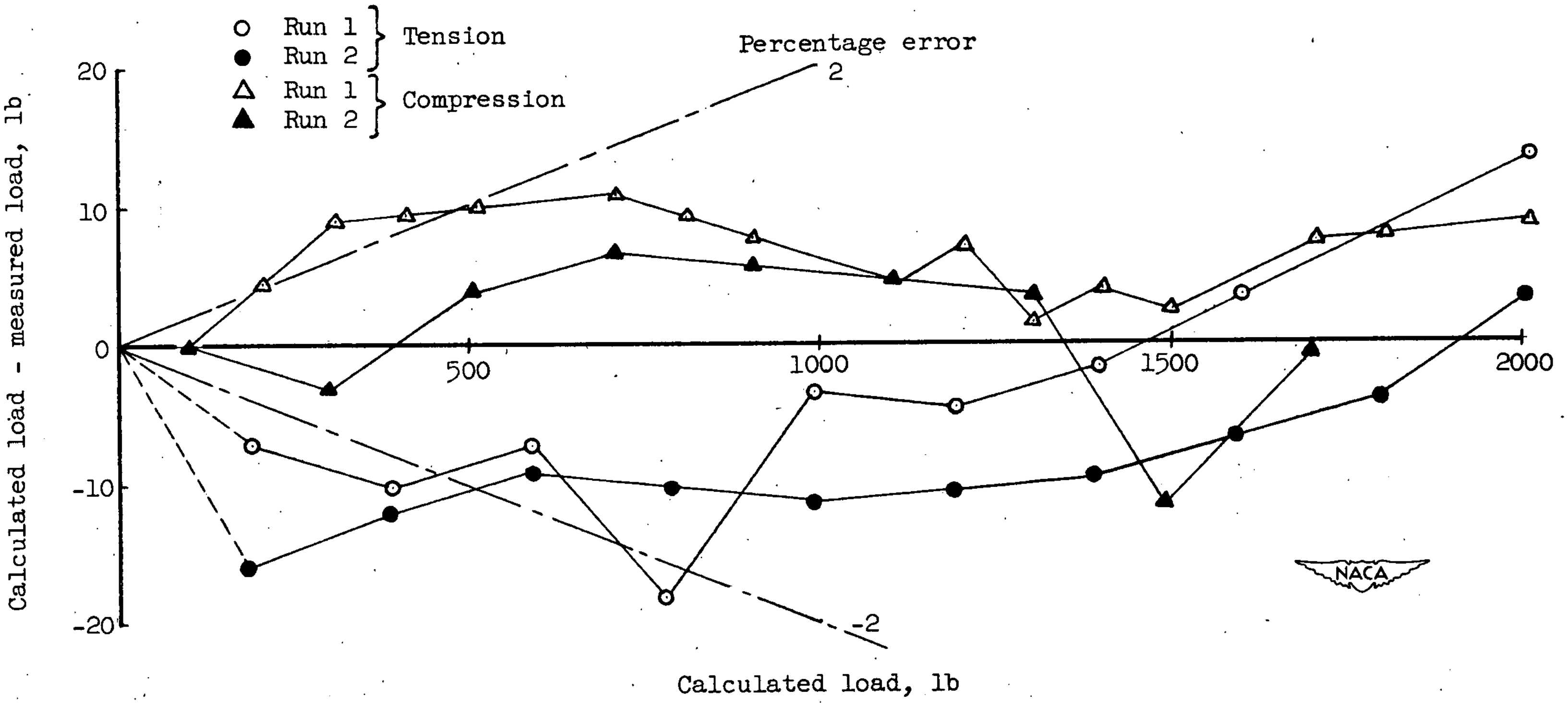


Figure 9.- Difference curves for dynamometer calibration. Calculated loads obtained from average least-squares equation, calculated load = $200.9\epsilon \times 10^4$, where ϵ is strain.

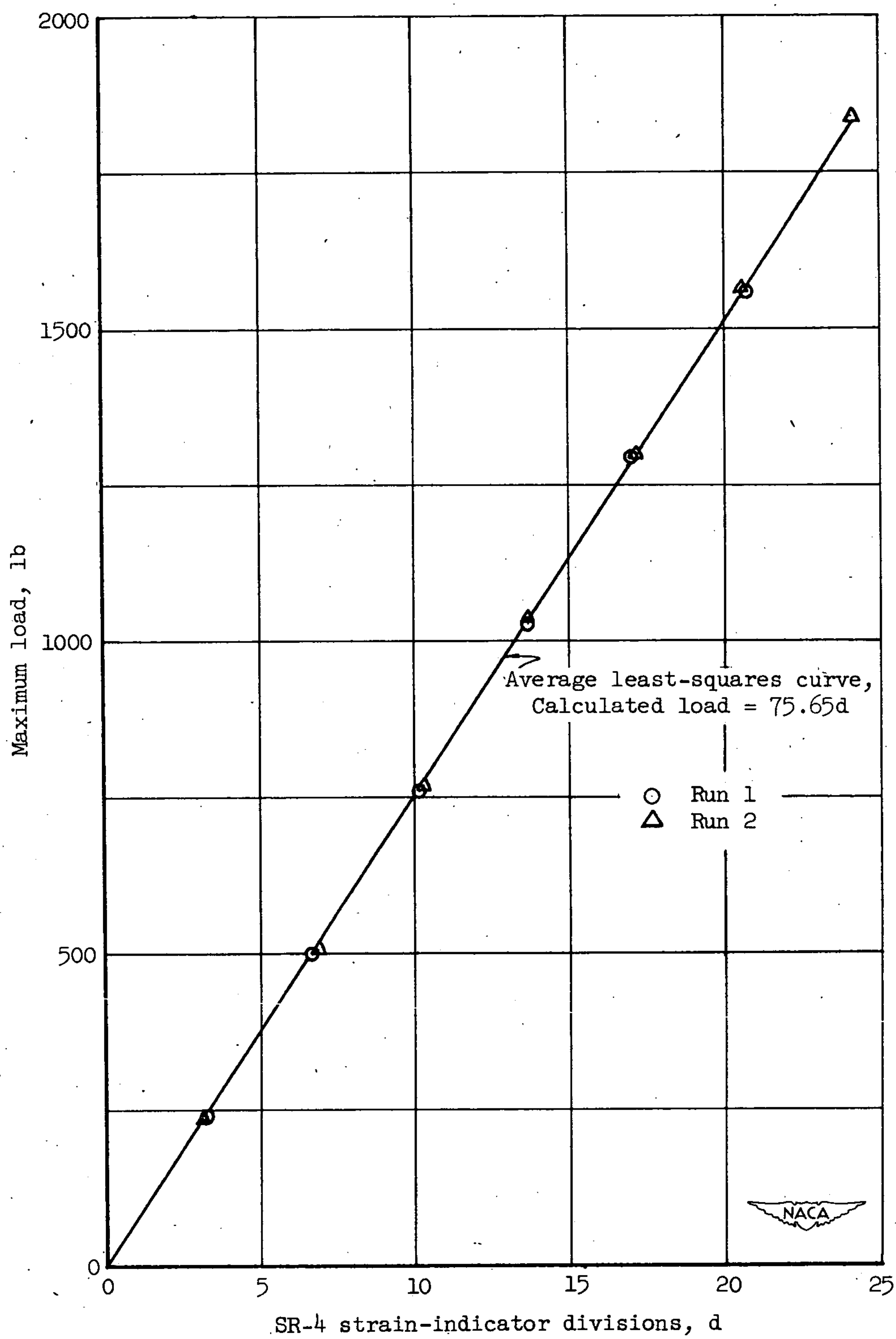


Figure 10.- Dynamic calibration of lever 1 of fatigue testing machine.

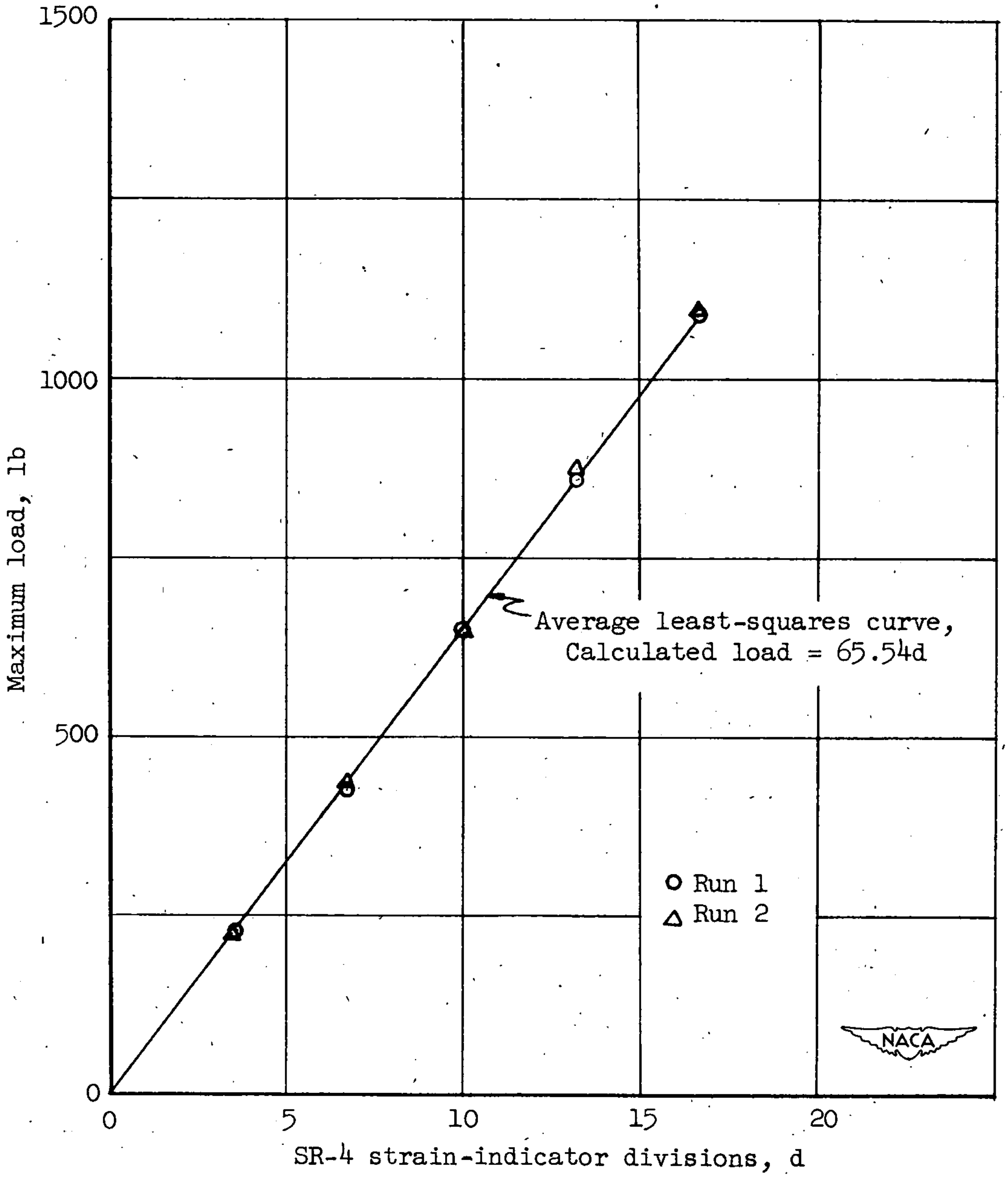
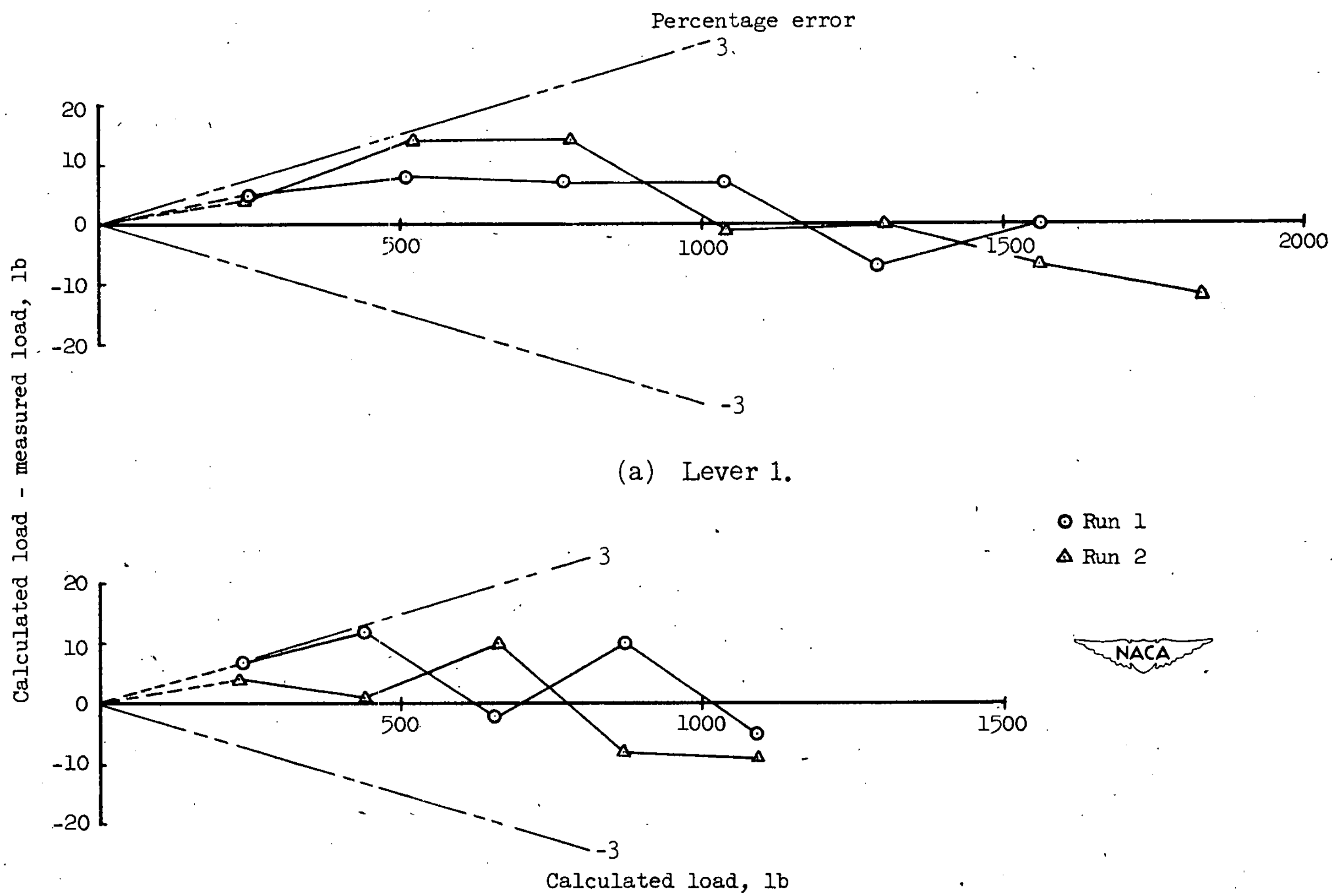


Figure 11.- Dynamic calibration of lever 2 of fatigue testing machine.



(b) Lever 2.

Figure 12.- Difference curves for calibration of levers of fatigue testing machine. Calculated loads obtained from average least-squares curves; measured loads obtained from dynamometer readings.

Materials, Properties - Fatigue 5.2.5

NACA

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(Abstract on Reverse Side)

Research Equipment, Materials 9.1.6

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Research Technique - Loads and Construction 9.2.4

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